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# SOLAR ENERGY SYSTEMS FOR MANUFACTURED HOUSING*

by

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## ABSTRACT

The opportunities for solar energy utilization in manufactured housing such as mobile homes and modular homes are discussed. The general characteristics of the manufactured housing industry are described including market and prices. Special problems of the utilization of liquid heating collectors, air heating collectors, or passive types of solar heating systems in manufactured housing are considered. The market situation for solar energy in manufactured housing is discussed. The design of the Los Alamos Scientific Laboratory mobile/modular home is described.

## I. INTRODUCTION

Manufactured housing such as mobile homes and modular homes presents an opportunity for solar energy utilization. This market is quite different than that of site-built housing and the differences must be taken into account in determining whether or not solar energy systems will be cost effective in this market. We have concluded that there are significant opportunities for reducing the cost of solar energy systems in the manufactured housing market, however there are also some characteristics of that market which require one to be very careful in assessing the marketability of these systems. One must be careful to identify the potential consumer who will be willing to consider the life cycle costing in his purchase of a solar heated manufactured house. We have concluded that the greatest opportunity for sales of solar energy systems in manufactured housing lies in the higher priced units, particularly the 24 ft wide units which are frequently manufactured in two 12 ft wide modules and assembled on-site. Systems which use air heating collectors or which use passive solar heating concepts may

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be able to be built for a lower cost and thus be more advantageous in the manufactured housing market, than systems with liquid-heating collectors.

## II. MANUFACTURED HOUSING

A manufactured house is one which is assembled in major modules or as a whole unit in a factory and transported over the highways to the desired location and then erected on the site. The major types of manufactured houses are designated as mobile homes, modular homes, prefabricated homes, panelized construction, etc.

In a mobile home the unit is built in such a way that it can be moved from the site by adding only a set of wheels and a draw bar at the front. This means that the major axial support structure for the home remains in place after the home is located on the site. The wheels may be taken off and the unit still remains, technically, a mobile home. Generally speaking mobile homes are purchased at prices of the order of $15 per sq ft by individuals who generally plan to live in them only for a few years. Eventhough they are generally not moved during their lifetime, there is comfort in the knowledge that the home can be moved.

Modular homes, by contrast, are usually more permanent structures. They are usually built in widths of 24 ft wide or more out of modules which are generally 12 ft wide. Modular homes generally sell in the price range of $16 to $20 per sq ft, delivered. The homes are frequently somewhat better insulated and better built than mobile homes. Modular homes are frequently set down on a stem wall or on a slab, and frequently conform to the Uniform Building Code and thus can qualify for longer term financing, such as 25 or 30 years.

Prefabricated homes, panelized construction, are other approaches which can be used to reduce costs by building major components such as wall sections in the factory and then assembling these sections on the site.

A brief history of market situation in the mobile home industry will give some interesting insite into the nature of that market today. During the period from 1947 up through about 1957 the market situation was dominated by 8 ft wide mobile homes. The total sales numbered approximately 80,000 per year during this period. During the next 8 year period from 1957 to 1965, 10 ft wide units dominated the market with total sales numbering approximately 100,000 per year. In 1961 double-wide units and 12 ft wide units were introduced into the market. By 1967, 12 ft wide units had captured roughly 85% of the market and the total number of all units sold numbered approximately 250,000. From 1967 to 1972 were incredible growth years for the mobile home industry with the total number of sales increasing to a high of 575,000 units. Fourteen foot units were introduced in 1968 and by 1972 accounted for 16% of the total market. The sale of double-wides had also grown to capture a total of 17% of the market by 1972.

Recession years, 1973 through 1975 had a drastic effect on the mobile home market. Sales dropped from a high of 575,000 units per year in 1972 to 213,000 units per year in 1975. During this same period single family housing construction dropped from 1,309,000 units per year to 829,000 per year, however, the mobile home industry was even harder hit dropping from 44% of this market to 25%. In 1976 it appears that the mobile home market may have stabilized. The growth rate over the last year has been around 30% with the total number of shipments in the first two quarters running about 250,000 units as a seasonally adjusted annual rate.

The composition of a mobile home market has changed very significantly during this period. Fourteen foot wide units now dominate the market making up about half of the total. Double wides and 12 ft wides constitute about one-quarter of the market each. In two significant states where 14 ft wide units cannot be shipped, California and Florida, the number of double-wides is roughly twice the number of 12 ft wide units. The vast majority of mobile homes are sold in the southern half of the United States, however there are significant sales in a few northern states.

Another welcome change is the more stringent standards imposed by the U.S. Department of Housing and Urban Development. Mobile homes are now more fire and wind resistant and generally much better insulated and constructed. This leads to a higher resale value. Many units are also built to be more in conformance with normal architectural styles and multiple-module units are frequently put together so as to be hardly distinguishable from site built homes. These units do cost more than the single wides but still far less than site built homes.

The entire mobile home industry is extremely competitive. A few hundred dollars difference in price can be very crucial in the sales of a mobile home. The average wholesale price of a 70 ft long by 14 ft wide mobile home is approximately $9,000, FOB factory. This is somewhat less than $10 per sq ft. Double-wides by comparison are aimed at a different market and cost appreciably more. They seem to be generally purchased by a buyer who is looking for better quality and plans to live for a longer time in the house.

Generally speaking, people think of mobile homes in mobile home parks. While this is true of most mobile homes (roughly one-half of all mobile homes are located in mobile home parks) there is a general trend toward location of double-wide mobile homes on standard lots in mobile home subdivisions or simply as individual buildings on all kinds of sites.

Another concept which is erroneous is that mobile homes are frequently moved. Most mobile homes are never moved once they are installed on a site. This is especially true of double-wide mobile homes--only about 1% of double-wide mobile homes are ever moved after they are installed on a site.

## III. SOLAR ENERGY SYSTEMS FOR MANUFACTURED HOUSING

Manufactured housing presents an opportunity for significantly lowering the installation costs of a solar energy system in a house. All of the reasons that manufactured housing costs less than site-built housing will apply to reducing the costs of the solar energy system in manufactured housing compared to site built housing. Let us look at these reasons.

1. Centralized buying. There are no middle-men in manufactured housing. Manufacturers buy in massive quantity direct from the producers.

2. Assembly-line construction. There is no waste time in a manufactured housing situation. Parts are at the right place at the right time. The units are built quickly and moved out quickly. Everything fits, there is no lost time in the trimming and fixing. The total construction time ranges from 1-1/2 days in a mobile home assembly line to a few weeks at the most on a modular home construction lot.

3. Lower wage costs. The labor market for manufactured housing generally receives lower wages than for site-built housing. When combined with efficiency of operation this holds the total labor costs to a small fraction of that for site-built housing.

All of the three above described advantages to manufactured housing also apply to the solar energy system in a manufactured house. Components can be centrally purchased in bulk and quickly assembled in routine fashion into the manufactured houses during construction.

One of the realities of solar heating has been a realization by all concerned that a predominant fraction of the cost of system installation is in components other than the collector--the piping, insulation, controls, storage, etc. The cost of all of these frequently exceeds the cost of the solar collectors. Much of this extra cost comes about because every installation is a special case, special time must be taken in fitting it together in order that it might work correctly, and in training a new group of people practically every time. Plumbing costs are especially high which leads to high costs for systems which use liquid heating collectors.

The three major types of solar heating systems which might be considered for manufactured housing are the following:

1. Systems which use liquid heating solar collectors, a water tank for thermal storage, and either forced air, radiant heating or convector heating for the heat distribution to the building.

2. Systems which use air heating collectors, a rock bed or other form of thermal energy storage, and forced air distribution to the building.

3. Passive systems which utilize natural means in order to achieve thermal energy flow.

The special problems and advantages of each of these types of systems in the scenario of manufactured housing situations will now be discussed.

The system which uses liquid heating collectors has the problem that the collectors are usually relatively expensive, costing $8 to $12 per sq ft of collector area. Many types of liquid heating collectors are on the market, most approaches have been tried by several different manufacturers, and it is unlikely that these costs will be reduced greatly even in a mass production situation. An advantage to the liquid heating collector system is that the thermal storage is an insulated tank of water. Although this tank is relatively large, from 500 to 1000 gallons, this will take up less space in the mobile home than the thermal storage of the other two types.

Systems which use air heating collectors are particularly attractive for manufactured housing. Air heating collectors can be built for from $4 to $6 per sq ft. An air heating collector system requires a great deal of attention to design and system layout in order to minimize amount of ducting and the amount of insulation used. This is no particular disadvantage in a manufactured housing market since this engineering and layout, once done, can be used repetitively and easily in the assembly line production. If anything, the manufactured house offers advantage in system compactness since the houses themselves are usually relatively compact.

Thermal storage for an air heating collector system presents a special problem for manufactured housing. The normal form of thermal storage for these units is a pebble-bed or rock-bed. A rock-bed can be located in the basement or underneath a house and is an unusually economical form of thermal storage. But where can a rock bed be located in a house which is to be transported over the road? Besides the question of weight, a rock bed also requires roughly three times the space of a water tank in order to achieve the equivalent thermal storage. One obvious solution is to locate the thermal storage underneath the mobile home by installing the rock bed in a pit underneath the mobile home and then moving the unit in place after the rock bed is finished and then connecting up the ducting appropriately. This solution has a number of disadvantages. One of the drawing points of manufactured housing is the minimum of site work and the speed with which the housing can be installed. The installation of a rock bed decreases this advantage. Another problem is that rock is not available at all sites, particularly in many locations throughout the southeast part of the U.S. where the mobile home market is very large indeed.

Another solution is to use water or a phase-change material in small containers to minimize space and weight. This has been done in the LASL mobile/modular home which will be described later.

Passive solar heating systems are not nearly so well developed or standardized, as the above two types of active solar systems. These systems operate on the principle that solar energy incident through glass in the home, can be stored directly by absorption into the thermal storage. The thermal storage may be in the floor, back wall, in a wall immediately adjacent to the window on the south side, or in the ceiling. Passively solar heated buildings have frequently used massive construction such as masonry for thermal storage. An attractive alternative is to use water in containers such as drums or bags for thermal storage. Incorporation of passive solar heating into manufactured housing presents an unusual design challenge. Massive building construction does not seem attractive since the houses must be portable. Water in containers (filled after location) may present an attractive option.

The market situation in mobile homes must be carefully assessed in judging the potential for solar energy utilization in this type of housing. I do not believe that there is a very significant potential for a market among the majority of buyers of the 12 ft wide and 14 ft wide mobile home units. Rather it would appear that the potential for market would be much larger among the buyers of double-wide units. These buyers are usually looking for a longer term investment in their housing. They are able to pay a larger price, they are planning to live in the house longer, and thus are able to consider life cycle costing in their approach to buying a house. Many buyers are older couples looking for a house for several years. These buyers are particularly concerned about future fuel costs and may be very willing to invest a few thousand additional dollars for protection against increasing fuel costs since they are usually living on a fixed income.

What price will the market pay? This, of course, is going to depend on fuel costs. Solar heating systems are probably not going to be competitive with natural gas prices until those prices go up by a factor of 3 or 4. It is my belief that solar heating systems can be built into mobile homes or modular homes at prices which are competitive with current costs of electric or propane heating.

Cost competitiveness depends not only on the initial cost but on the financing arrangements that can be made by the purchaser of the unit. If the unit is financed as a mobile home with 15-year financing at interest rates of 12%, the situation is quite different than if it is financed as a modular home over a period of 30 years at interest rates of 9%. The monthly payment is 49% greater in the first case than in the second case. Thus, if the add-on costs of the solar heating system is financed along with the home, the effective cost of solar heat to the home owner, would be 49% greater in the first case than in the second case. Thus, if the add-on costs of the solar heating system is financed along with the home, the effective cost of solar heat to the home owner, would be 49% greater in the first instance than in the second instance if the add-on cost of the solar heating system is the same in both cases. This is another reason for considering that there is a more fertile market for solar heating systems in double-wide mobile homes than in single-wides, since it is usually the double-wide mobile homes which can be qualified for longer-term, lower-interest financing.

## IV. THE GENERAL ELECTRIC MOBILE HOME PROJECT

The first effort sponsored by the Federal Government to investigate the application of solar energy to mobile home heating and cooling was by The General Electric Co. Funding for this project was initiated under the National Science Foundation and has been continued under the Energy Research and Development Administration. The approach used by General Electric was to modify a 12 ft by

60 ft mobile home built by the Skyline Corp. The solar heating system utilizes a liquid-heating collector which is added on to the roof of the mobile home and uses water in tanks located in the frame support beneath the mobile home for thermal storage. A solar cooling system was also added to the mobile home unit by incorporating a lithium-bromide absorption chiller into the mobile home and rejecting the heat from that chiller through a cooling tow. on the outside. The heat supply for the absorption chiller was from the solar heated hot water.

The project demonstrated the technical feasibility of the concept. I have serious reservations about the economic feasibility of the particular approach used since the total add-on cost of the solar heating and cooling system may well be comparable to the initial cost cf the mobile home itself.

The mobile home has undergone a series of successful tests at several locations. In addition, the mobile home has been shown extensively at mobile home fairs. The unit has recently been modified to incorporate a Rankine-cycle type of cooling unit that was designed by General Electric. This Rankine cycle unit is being tested as a possible alternative to the absorption-type of unit which was initially installed.

## V. THE LOS ALAMOS SCIENTIFIC LABORATORY SOLAR MOBILE/MODULAR HOME PROJECT

The Los Alamos Scientific Laboratory (LASL) is investigating the application of solar energy to mobile/modular home heating and cooling through the testing and evaluation of a series of prototype solar heated and cooled homes. Pr.ject funding is from the Division of Solar Energy of the U. S. Energy Research ar. Development Administration.

As the country's first solar energy system designed especially for mobile/modular homes, the project may have far reaching effects for the housing industry. The market for this type of housing is expanding rapidly and is projected to account for nearly one-third of the total U.S. single family dwellings in the near future. The small number of manufacturers, and the ease with which a solar heating and/or cooling system can be factory integrated into these units, offer a unique opportunity for immediate and large scale reduction of domestic fossil fuel consumption at a low cost to the consumer.

LASL's development plan for solar heating and cooling of mobile/modular homes calls for the design of four prototype units with each unit emphasizing different techniques for different climates. In conju.ction with home manufacturers, LASL will be designing, building, testing, evaluating, and demonstrating the complete series of prototypes. Each prototype is being designed to accomplish the technical objectives of developing cost effective solar heating and/or cooling for manufactured homes.

The first unit, which has already been built, incorporates an active solar heating system into a double-wide mobile/modular home. The second unit will also be solar-heated, but it will utilize a passive system as opposed to an active one. A passive system is one which operates automatically without external energy inputs using direct energy transfer and natural convection as opposed to an active system which uses separate collectors and thermal storage and requires electric pumps or fans to transfer the heat. Combined solar heating and cooling systems will be incorporated into the latter two units. Each unit will also include the solar heating of domestic hot water.

## A. Description of Unit One

The project's first prototype unit is an attractive solar heated mobile/ modular building located at a Los Alamos technical area site. It is a small three bedroom house with 1-1/2 baths, a living room, kitchen, furnace room, utility room, and several closets. The dimensions are 24 ft wide by 44 ft long making up a total of 1056 sq ft. Designed as a relocatable structure, the unit can be designated as either a mobile or modular home depending on its foundation. As a modular home, it will conform to the Uniform Building Code and qualify for normal home financing.

The basic structure of the home is conventional wood frame construction. A special truss structure was designed in order to provide for the 60° sloping collector array on the south side of the building. Designed to minimize heat loss and air leakage, the home has 4 in. of fiberglass insulation in the walls, about 10 in. in the ceiling, and 8 in. in the floor. Solid core exterior doors, double pane glass windows, and double pane sliding doors are used to reduce energy consumption. Five narrow windows are interspersed between collector panels on the south walls to provide additional daylight to the living areas. The building's physical layout reflects the special requirements of highway transportability and of solar energy utilization.

The solar heating system utilizes air heating collectors and a bin of glass jars filled with water for thermal energy storage. This should provide approximately 80% of the space and domestic hot water heating for the house located in the 7000 degree-day (DD) Los Alamos climate.

A 17 panel array of collectors provides for solar hot air heating for the system. Each panel is 2 ft wide by 10 ft long making up a total collector area of 340 sq ft. Factory assembled in accordance with LASL's specifications, the panels are fastened directly to the sloping south wall of the home and attached together by a steel cap strip to form a weather tight roof/wall structure. They are insulated from the house by a 2 in. fiberglass matte, the plywood deck fastened to the trusses, and a 6 in. layer of fiberglass within the truss space. The collectors are made of galvanized steel and have a double-strength single-pane glass cover which is sealed with a silicon rubber gasket. For sunlight absorption, the exposed metal surface is painted with a flat black paint. The 60° angle slope of the collector array is a reasonable choice for any location within the United States.

One of the most unique aspects of the design is the thermal storage system which was constructed specifically to fit into a minimum of space in a 4 ft by 10 ft furance room. The thermally insulated storage bin occupies the bottom section of this furnace room up to a height of 30 in. It is filled with 1536 pint glass jars filled with ordinary tap water, sealed, and stacked in four rows for heat storage. Heat is transferred from the solar heated air to the water by flowing around the jars which are stacked about 2/3 in. apart. The complete package fits in a space that a conventional freezer might occupy. This compact system will store sufficient energy to provide 6 to 10 hours of useful heat on a cold night. An electric furnace provides the backup system for those periods when there is a series of cloudy days.

Domestic hot water is also provided in the system design. Integrated in the collector hot air return is a hot water finned copper coil. Water preheated by the heat transfer coil is stored in a 52 gallon solar pre-heater tank. From the pre-heater tank, the water goes to a 30 gallon tank in which it can be heated up to higher temperatures by the electric furnace if necessary. On sunny days, the temperature of the water in the solar pre-heater tank ranges from 120 to 150°. With a design capacity of 22 gal/person/day at 125°F, this system is designed to produce 85% of the hot water heating requirement based on a national average family size of 3.7 persons.

Unit one was designed as a part of the on-going solar research being directed by the Solar Energy Group of Q-Division at LASL. Industrial and Systems Engineering, Inc., (I.S.E.) of Albuquerque, was the prime contractor for the project and performed the solar system design and integration under the direction of the Solar Energy Group. Designs for the unit were executed by Burns and Peters, an Albuquerque architectural firm, and Aztech International Ltd., Albuquerque constructed the air collectors as designed by LASL. The unit was manufactured by Albuquerque Western Industries, Inc., (A.W.I.) under a subcontract to I.S.E. Albuquerque Western Industries manufacturers mobile/modular homes for the New Mexico market.

B. Thermal Performance

The thermal performance of any solar system depends upon its location and the building's thermal load. Within the constraints imposed by a relocatable structure, the thermal load of the first mobile/modular unit was minimized by adequate insulation, double glazed windows, control or infiltration, and some passive solar gains. At present, the unit is located in Los Alamos, NM at a latitude of 35.8° north and an altitude of 7000 ft where the winter climate is cold but sunny with appreciable snowfall.

The measured heat load for the unit is 7.5 BTU/DD/sq ft. This means that for an outside temperature of 0°F and an inside temperature of 70°F the building heat load will be 7.5 x 1054 x 70 = 552,000 BTU/day or 23,000 BTU/hr.

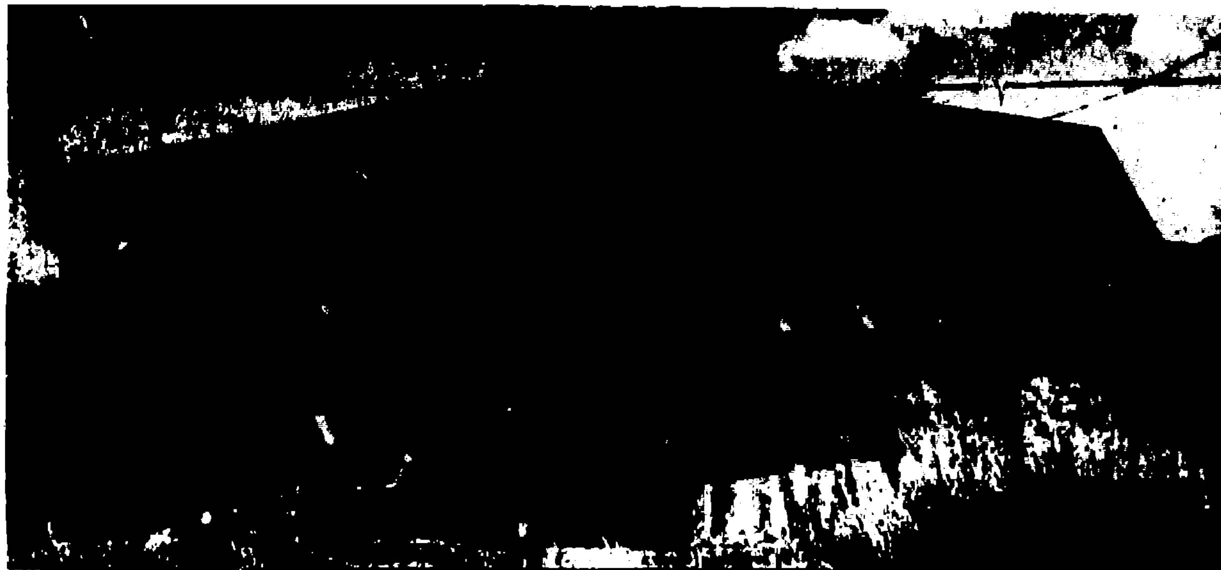
Extensive computer simulations have been used to model the thermal performance of the unit in Los Alamos using the observed weather and solar data. The actual system is simulated by a digital computer code on an hour-by-hour basis. At each hour the net energy which can be extracted from the collector array and the thermal load are calculated. The change in storage temperature over the hour is the net energy added from the collector minus storage heat losses minus the energy extracted by the thermal load, divided by the storage heat capacity. This calculation is repeated for each of the 8,760 hours of the year.

The summary of the simulated solar performance for the complete year gives 79% solar heat for the unit for 6600 DD. Simulations for other locations are shown in the following table along with the degree-day heating load for the particular year which was simulated.

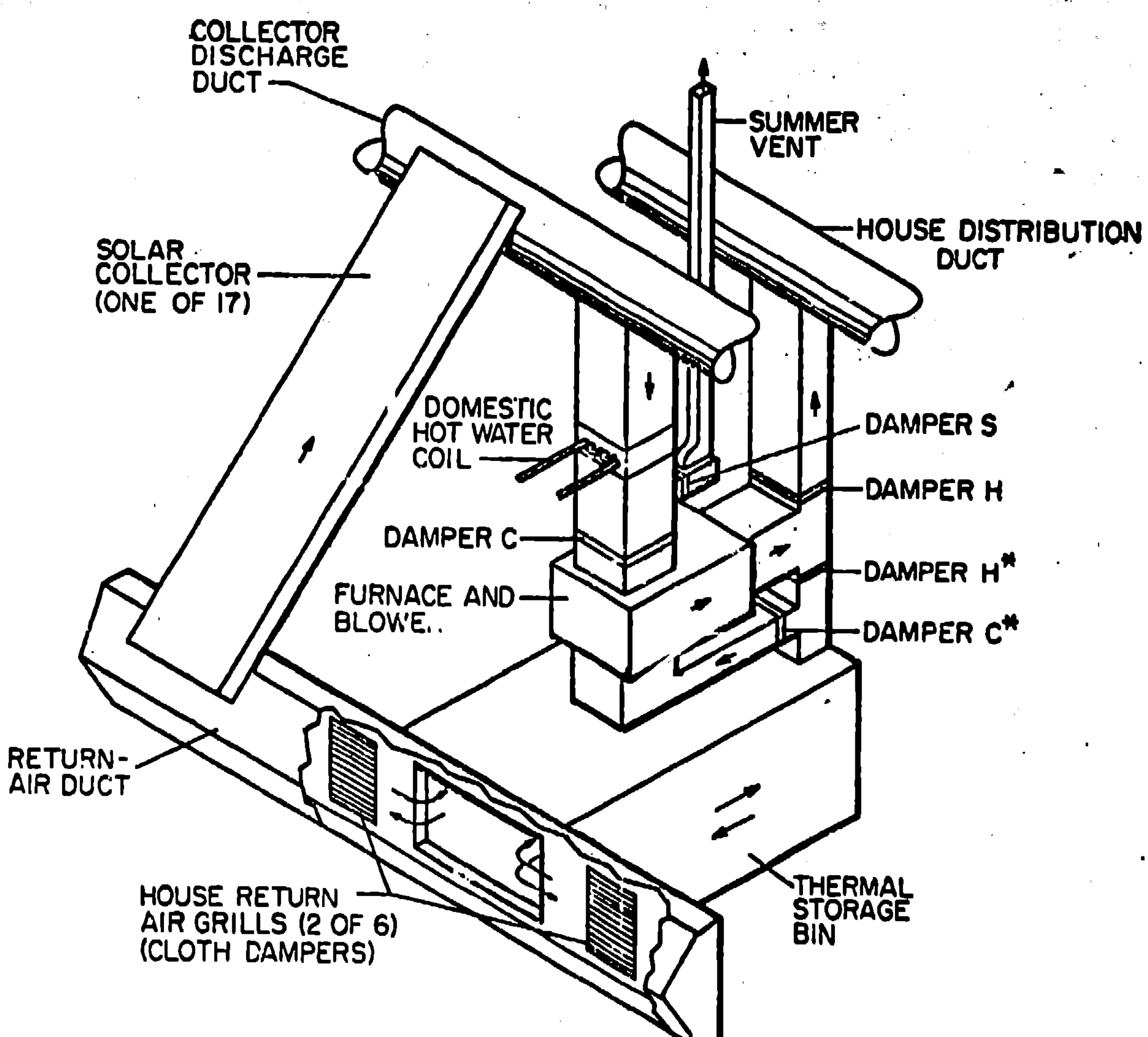
| City | Percent of Total Heat from Solar | Heating Degree Days |
|---|---|---|
| Phoenix, AX | 100 | 1278 |
| Fresno, CA | 96 | 2622 |
| Los Angeles, CA | 100 | 1700 |
| Santa Maria, CA | 98 | 3065 |
| Miami, FL | 100 | 272 |
| Tallahassee, FL | 99 | 1783 |
| Dodge City, KS | 79 | 5199 |
| Lake Charles, LA | 92 | 1694 |
| Boston, MA | 64 | 5535 |
| Medford, MA | 67 | 5275 |
| Lincoln, NE | 71 | 5995 |
| Bismarck, ND | 56 | 8234 |
| Albuquerque, NM | 93 | 4235 |
| Los Alamos, NM | 79 | 6604 |
| New York, NY | 65 | 5221 |
| Nashville, TN | 73 | 3805 |
| El Paso, TX | 73 | 2496 |
| Ft. Worth, TX | 84 | 2467 |
| Charleston, VA | 93 | 2279 |
| Seattle, WA | 60 | 5143 |
| Madison, WS | 54 | 7838 |
| Edmonton, Canada | 41 | 11527 |
| Fredericton, Canada | 48 | 8834 |
| Ottawa, Canada | 45 | 8832 |
| Vancouver, Canada | 63 | 5909 |
| Winnipeg, Canada | 37 | 11242 |

## C. Cost Estimate

Estimated total cost of the prototype solar heated unit is approximately $39,000. Based on the production rate of one unit per week, it is believed that the unit could be produced for around $25,000. Without solar heating, a mass produced unit would cost around $20,000 with the same insulation as the prototype. Solar add-on costs therefore are approximately $5,000. The solar collector panels at about $6.50 per sq ft would cost around $2,000, and that leaves $3,000 in the balance of the system including structure, ducts, blowers, thermal storage, controls, etc.



Los Alamos Scientific Laboratory Solar Heated Mobile/Modular Home.




Isometric Schematic of the Solar Heating System.